HYBRID TOA/RSS ALGORITHM FOR INDOOR LOCALIZATION

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Abstract

The indoor localization, in general, suffers from several challenges, such as the reflection of signal, diffraction, and attenuation. With these problems, the error range is increased significantly and the accuracy will be reduced. To address those problems, a hybrid localization algorithm was proposed in this paper which aims to get the localization and estimation of several received points within the selected study area. Such algorithm was based on the use of Time of Arrival (ToA) and Received Signal Strength (RSS), which have been calculated via Wireless InSite (WI) software. The proposed algorithm works based on the Gaussian Newton algorithm (GNA). The results obtained showed higher accuracy in indoor environment localization, and accurate results for the coordination estimation and the separation distances between the AP's and Rx points.

Keywords

Localization, ToA, RSS, Hybrid &Wireless InSite

1. INTRODUCTION

The technology based indoor localization have gain wide emerging in our everyday life, particularly with the applications of smartphones and the Internet of Things (IoT). One of the most interesting technology was the position based systems where the position estimation could be considered as the most interesting aspect for IoT based application [1]. Such technology could be used in the airports, traveling stations, supermarkets, to handle the purpose of tracking and finding the positioning of someone [2]. The Global Position System (GPS) has been utilized widely and effectively for localization and positioning estimation for outdoor environment. However, performing it for indoor environment has resulted in a wide range of challenges and drawbacks [3]. The most important challenges were due to the small area within indoor environments and the effect of different obstacles, objects and walls, which will effect on the signal availability and the efficiency of the used system in perform positioning and localization issues [4]. Hence, localization based indoor environment has been considered to be difficult to perform due to several reasons related with the complexity of such environment like the effects of reflection, diffraction and the serious effects of different walls located inside the indoor environment [5,6]. As a result, the researchers started using a new concept and involve it with different indoor localization issues, which is the Wireless Fidelity (Wi-Fi) [7,8,9].

Wide range of methods and aspects were presented by researchers for different localization estimation based indoor environment. For instance, methods based on the Time-of-Arrival (TOA), proposed by several researchers as in [10,11,12], with accurate results achieved by their works. However, using TOA method must perform synchronization between the target point and the reference points. Meanwhile, another astonishing method was based on the Angle-of-Arrival (AoA) method, which has been used in many academic researchers as in [13]. Lower accuracy results achieved by this method. In addition, it brought several drawback as it requires extra cost and time. On the other hand, Time Difference of Arrival (TDOA) was another important method to be follow by many researchers as in [14]. The basic concept of such method was depending on the received signal time at two reference points and the speed of signal travelling between the target and the reference points. Then, the differ in arrival time would be lead to obtain the difference in distance. Meanwhile, groups of researchers presented method based on the Received Signal Strength (RSS) as in [15, 16, 17, 18, 19]. Such method has interested by researchers recently, due to many reasons of doesn’t require extra implementation costs. However, a lower accurate results has been reported to be achieve using this method in indoor localization. All these methods would be estimate the separated distance between known Reference Points (AP) and unknown targets (Rx), the position obtained depending on methods such as the trilateration or triangulation. However, there are many limitations and constraint which restricted the reliability, accuracy and overall efficiency such as, huge multipath and wide band of noise emitted from other wireless communication system and electric devices. The paper is divided as follows. TOA&RSS measurement and Measurement methodology was discussed in section 3 and 4 respectively. The results and discussion discussed in section 5. Finally, the conclusion is drawn in section 6.

2. RESEARCH METHOD

Several localizations based systems methods have been constructed by researchers and industries. In this section will focus on TOA and RSS methods as a related method for our proposed algorithm. For example, in [8] it has been proposed a system for localization and positioning within indoor environment and based on the use of Wi-Fi technologies. The utilization of such technology was based on its higher reliability and availability with smart-phones and other devices. The proposed system has been implemented with two scenarios. The first was the offline stage where the data has been obtained and gathered in the database. The values stored in this database would represent the reference value. While, second stage was the real-time measurements for movement targets. The results obtained showed high effectiveness on measurements which leads to a highly accurate system. In addition, in [19] the authors another system implemented by utilizing the Wi-Fi technology, where it has been used path loss to obtain the desired distance between the AP and Rx points. Such distance represents the separation between the known points denoted as reference points and the targets. They used the trilateration method to estimate the last estimation coordination based on the distance which has been measured. Furthermore, in [7] it has been proposed a localization system for indoor environment by using deep learning. Particularly, in localization there is two phases of online and offline. For first phase, fingerprint database build from the RSS measurement. While for the second phase, an algorithm would be matching the real measurements with a database to adopt those measurements. The different in measurements would showed a significant decrement in estimation error. Another interesting work has been performed in [9] by proposed a method for Wi-Fi based localization, where three AP were deployed in the interested area to estimate the location of the target and by using trilateration method. Results obtained showed encourage estimation. In the recent years, researchers start working in a hybrid approaches for localization. Such as the RSS/TOA based method as in [20] and based on the use of likelihood function to perform localization in Wireless Sensor Network (WSN). However, such localization based these methods didn’t consider the effects of different building materials, structure and objects that may face any typical indoor environment. In addition to that a hybrid method based on TDOA/RSS has been proposed as in [21] and based on the use of Bisection procedure for location estimation. In line with all these contributions, in this paper it has been proposed a hybrid algorithm based on the use of TOA/RSS for indoor localization. The algorithm and case study have been modeled and tested using the 3D Ray-Tracing Wireless InSite (WI) software. The presented method has considered the effects of different building materials inside the building and the frequency sensitivity materials to make higher accurate results and reduce the estimation errors.

3.HYBRID LOCALIZATION ALGORITHM BASED TOA & RSS

3.1. General Consideration

The major concept related with our proposed algorithm for localization implies on the trilateration based method where set of fixed AP devices would be used to localize different received point (Rx) and based on the distance measurement. Such distances, would be obtained from the Euclidian distance formula, as illustrate in Fig. (1) and equation (1). For instance, three distances are needed to satisfy the trilateration based method and as can be seen in Fig. (2). However, in a more complicated scenario for network-based radio localization these obtained distances values are not directly measurable, but have to be estimated from a wider set of observed data; typically, the data exchanged between the AP and the Rx. The time of arrival (ToA) for each path propagated between the AP and Rx would be calculated based on equation (2). [19]

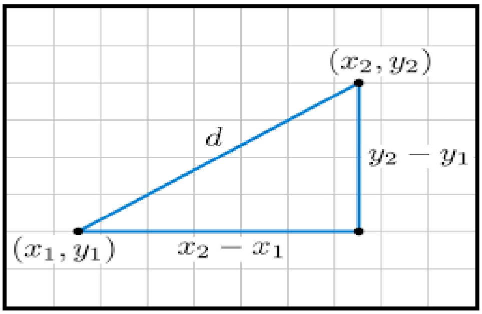


Figure 1. Euclidian distance concept

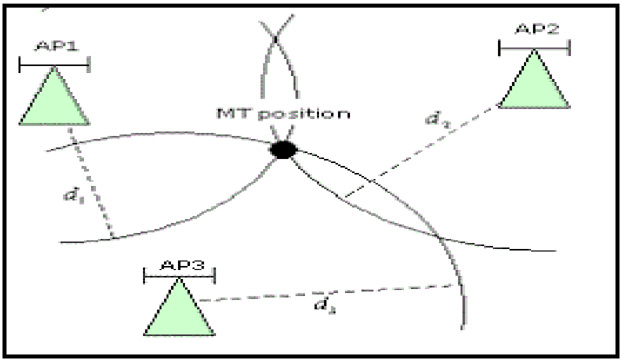


Fig 2. Localization of ToA based on trilateration concept

$$Distance\ estimated = \sqrt{(\mathrm{xi} - \mathrm{x}k)^2 + (\mathrm{yi} - \mathrm{y}k)^2} \qquad (1)$$

$$\mathrm{ti} = \frac{\text{Distance estimated}}{\mathrm{c}} \qquad (2)$$

Where ti is the ToA value, Distance estimated represent the total geometrical path length, c is the speed of light, (xk, yk) represent the coordination of AP and (xi,yi) represents the coordination of each Rx point within our scenario. On the other hand, RSS has been known as one of the most interesting method for localization, which could be represented as the power strength transmitted between the AP and the Rx. RSS has been obtained based on equation (3) given by [22]

$$RSS = \sum_{i=1}^{NP} \frac{\lambda^2 \beta}{8\pi\eta_0} \left| E_\theta, ig_\theta(\theta i, \Phi i) + E_\Phi, ig_\Phi(\theta i, \Phi i) \right|^2 \qquad (3)$$

Where λ is the wavelength, β is the overlapping of the frequency spectrum, η0 is the free space impedance, E_θ, i and E_Φ, i are the theta and phi components of the electric field of the ith path at the receiver point, NP is the path's total number and finally θi,Φi represent the direction of arrival. It is worth to mention, that for practical real measurement scenario, RSS would have represented by the value of the transmitted power summed with the total noise and interference effects achieved by each transmission and as expressed in equation (4) [23].

$$\text{RSS Practical} = \text{RSS} + \text{I}_{\text{Total}} + \text{N}_{\text{Total}} \quad (4)$$

Where RSS the value of the received power is obtained from the received point, I_{Total} and N_{Total} represents the total interference and noise in the system respectively.

3.2. The proposed Algorithm

Our proposed algorithm considers the hybrid method of RSS and ToA, where the data collected from WI software would represent the RSS value obtained from every path located between the AP and each Rx points, the value of ToA in (ns). It is worth to mention, that the optimum path with all its related parameter would be obtained based on previous software designed and proposed in previous work. The parameters of optimum path would be stored in the database to be handled within our proposed algorithm.

Out algorithm has been designed in MATLAB program, the procedure of it would be summarized into the below steps:

Step 1: the first step is to enter the number of AP and Rx points and entering the total area size. A total number of 400 iterations has been selected for our algorithm procedure and along with the Gaussian Newton Algorithm (GNA), which has been considered as the basis of our proposed localization algorithm.

Step 2: Then in the next step the estimated distance (Distance estimated) per each Rx point would be calculated based on equation (1) and (2).

Step 3: Furthermore, the distance derivatives (Deriv. Distance) would be calculated based on equation (5) and for both x and y coordination.

$$Deriv.Distance = \frac{x1(i)-x(k)\ /\ Distance\ estimated}{y1(i)-y(k)\ /\ Distance\ estimated}$$

(5)

Where i represent the number of Rx points and k represent the number of AP devices.

Step 4: The Δ (Delta) would be calculated in the next step as clarify in equation (6). For the Distance Noise it has been obtained it based on the value of distance measurement error ratio, which has been selected previously to be equal to (0.05).

$$\Delta = (-(Deriv.Distance * Trans(Deriv.Distance))^{-1*Transpose(Deriv.Distance)*(Deriv.Distan}$$
(6)

Step 5: The Rx coordination of x and y would be obtained in the final step and based on equation (7) and (8) respectively. Finally, after completing the total number of Rx points and the entire selected iteration.

$$Estimated\ Rx\ Coordination, x1(i) = Distance_{\ estimated} * Transpose\ (\ \Delta) \quad (7)$$

$$Estimated\ Rx\ Coordination, y1(i) = Distance_{\ estimated} * Transpose\ (\ \Delta) \quad (8)$$

Step 6: A final figure would be withdrawn to clarify the actual Rx coordination and the estimated coordination from the previous step.

4. Case Study

An indoor based case study has been selected for our proposed algorithm, which is the 2nd and 3rd floor in the building of electrical department of University of Technology, where it has been designed, modelled and simulated it by using the WI software as clarified in figure 4. It has been distributed a total of three AP devices with 2.5 m height of the selected floor to perform the localization as a reference point. Meanwhile, it has been distributing a total of 11 and 10 target points (Rx) to be localize within the 2nd and 3rd floor respectively. The distribution map for both AP's and Rx points can be seen in figure 5. The parameter selected for antennas of both AP and Rx has been listed in table1. In this study, it has been considered the effect of building materials, structure and the frequency sensitivity material on the accuracy of localization and wave propagation to achieve a reliable algorithm to be considered the 3-Dimension (3D) investigation. Such consideration would be based on the obtaining of the value for Relative Permittivity (ε) and Conductivity (σ) for each utilized material in our case study and as listed in table 2. This consideration was to meet the requirements of the International Telecommunication Union (ITU) [24].

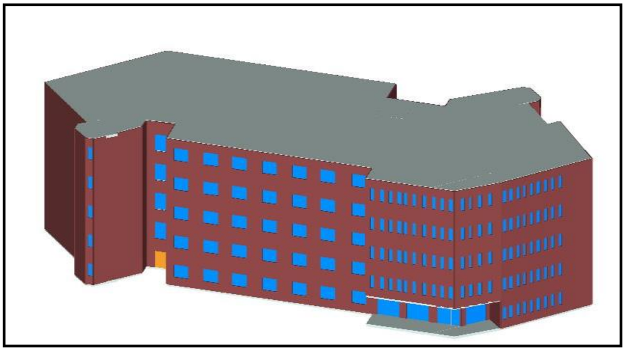
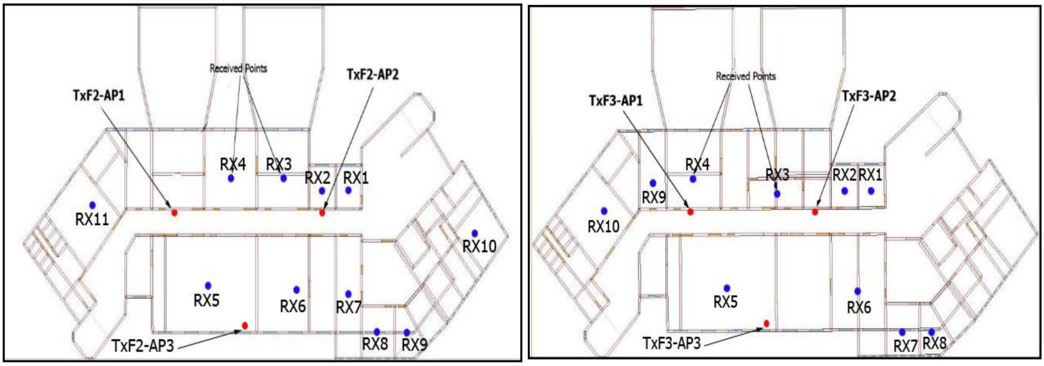


figure 4. the simulated case study building



(a) (b)

Figure 5. The distribution of AP's and received points per (a) 2nd floor and (b) 3rd floor

Table 1. The antenna parameter for both Tx and Rx

Antenna properties	AP	Rx
Type of Antenna	Omni	Omni
Power (dBm)	30	-
Antenna Gain (dBi)	9	2
E-Plane HPBW	90°	90°
Waveform	Sinusoid	Sinusoid
VSWR	1	1

Table 2. The parameters utilized for each material within our case study

Materials	Thickness (m)	ε : σ
Concrete	30	5.31 : 0.066
Wood	4.5	1.99 : 0.012
Glass	0.3	6.27 : 0.012

5. RESULTS AND DISCUSSIONS

The performance of our proposed algorithm has been evaluated based on the values of optimum RSS, ToA and the separation distance located between each AP to each Rx point that obtained from the software of WI. The optimum path based on RSS measurement, the ToA value and the distance separating have been selected to be performed with our proposed algorithm and as listed in Table 3 to form our database for the proposed algorithm.

Table 3. The parameter values obtained from each AP in both 2nd and 3rd floor and for each Rx point

Received Point		AP1			AP2			AP3		
		Optimum RSS	TOA	Distance	Optimum RSS	TOA	Distance	Optimum RSS	TOA	Distance
second floor	Rx1	-55.83	1.05E-07	31.16	-37.17	1.62E-08	4.86	-59.96	7.26E-08	21.78
	Rx2	-55.83	7.88E-08	23.55	-21.05	9.77E-09	2.93	-58.78	6.38E-08	19.15
	Rx3	-53.46	6.21E-08	18.5	-38.99	5.58E-08	16.35	-60.92	5.83E-08	17.48
	Rx4	-40.22	4.09E-08	12.07	-52.81	5.54E-08	16.47	-43.67	5.59E-08	16.76
	Rx5	-29.64	3.20E-08	9.59	-49.56	6.48E-08	19.43	-17.25	2.61E-08	7.83
	Rx6	-37.15	6.92E-08	20.69	-29.44	3.22E-08	9.68	-28.74	2.89E-08	8.69
	Rx7	-62.88	1.01E-07	30.04	-40	5.05E-08	14.71	-43.3	5.23E-08	15.7
	Rx8	-58.23	1.12E-07	33.65	-54.63	5.47E-08	16.19	-54.49	6.65E-08	19.9
	Rx9	-81.55	1.26E-07	37.85	-32.6	7.50E-08	22.33	-64.22	8.11E-07	24.27
	Rx10	-67.51	1.52E-07	45.7	-68.02	8.27E-08	24.38	-79.37	2.03E-07	60.66
	Rx11	-26.97	4.68E-08	13.93	-42.23	1.18E-07	35.57	-45.44	9.22E-08	27.63
third floor	Rx1	-55.28	9.09E-08	27.18	-37.86	4.94E-08	14.43	-59.19	8.31E-08	24.82
	Rx2	-53.99	9.14E-08	27.05	-27.19	2.95E-08	8.63	-58.56	6.49E-08	19.56
	Rx3	-40.79	7.86E-08	14.45	-27.58	3.10E-08	9.07	-42.71	5.05E-08	15.15
	Rx4	-22.67	1.38E-08	4.15	-47.59	6.82E-08	20.2	-44.83	7.22E-08	21.47
	Rx5	-30.13	3.41E-08	10.22	-42.06	5.37E-08	15.95	-16.72	2.44E-08	7.33
	Rx6	-41.07	9.49E-08	28.17	-30.92	3.70E-08	11.11	-32.11	4.58E-08	13.74
	Rx7	-54.11	1.22E-07	36.28	-47.34	6.27E-08	18.8	-45.04	6.66E-08	19.97
	Rx8	-76.91	1.26E-07	37.92	-34.72	8.93E-08	26.61	-56.7	8.12E-08	24.34
	Rx9	-38.21	3.48E-08	10.21	-56.25	8.34E-08	25.2	-37.79	8.81E-08	26.19
	Rx10	-32.23	4.28E-08	12.48	-39.81	1.03E-07	30.88	-58.51	9.06E-08	27.18

In contrast, the estimated separated distances were the second part forming our evaluation procedure, which has been obtained from our proposed algorithm. The actual, estimated distances and the distance error were listed in Table 4 and 5 for both 2nd and 3rd floor respectively. It can be noticed that the minimum distance error obtained from the three AP was 0.06 and 0.05 m for 2nd and 3rd floor respectively. While the maximum distance error was 0.5 and 0.47 m for 2nd and 3rd floor respectively, which indicating the higher accuracy of our proposed localization algorithm.

Table 4. values of Actual distance, estimated distance from our hybrid algorithm and the error distance for 2nd floor scenario.

Received Point		Second floor estimation		
		Actual distance	Estimated distance	Distance error
AP1	Rx1	31.16	30.9	0.26
	Rx2	23.55	23.45	0.1
	Rx3	18.5	18.2	0.3
	Rx4	12.07	11.9	0.17
	Rx5	9.59	9.4	0.19
	Rx6	20.69	20.32	0.37
	Rx7	30.04	29.95	0.09
	Rx8	33.65	33.45	0.2
	Rx9	37.85	37.46	0.39
	Rx10	45.7	45.2	0.5
	Rx11	13.93	13.8	0.13
AP2	Rx1	4.86	4.75	0.11
	Rx2	2.93	2.8	0.13
	Rx3	16.35	16.12	0.23
	Rx4	16.47	16.11	0.36
	Rx5	19.43	19.21	0.22
	Rx6	9.68	9.55	0.13
	Rx7	14.71	14.65	0.06
	Rx8	16.19	16.01	0.18
	Rx9	22.33	22.11	0.22
	Rx10	24.38	24.03	0.35
	Rx11	35.57	35.41	0.16
AP3	Rx1	21.78	21.69	0.09
	Rx2	19.15	19.01	0.14
	Rx3	17.48	17.14	0.34
	Rx4	16.76	16.45	0.31
	Rx5	7.83	7.54	0.29
	Rx6	8.69	8.52	0.17
	Rx7	15.7	15.4	0.3
	Rx8	19.9	19.7	0.2
	Rx9	24.27	24.11	0.16
	Rx10	60.66	60.54	0.12
	Rx11	27.63	27.45	0.18

Table 5. values of Actual distance, estimated distance from our hybrid algorithm and the error distance for 3rd floor scenario.

Received Point		Third floor estimation		
		Actual distance	Estimated distance	Distance error
AP1	Rx1	27.18	26.95	0.23
	Rx2	27.05	26.88	0.17
	Rx3	14.45	14.3	0.15
	Rx4	4.15	4.03	0.12
	Rx5	10.22	10.11	0.11
	Rx6	28.17	27.96	0.21
	Rx7	36.28	36.04	0.24
	Rx8	37.92	37.86	0.06
	Rx9	10.21	10.1	0.11
	Rx10	12.48	12.43	0.05
AP2	Rx1	14.43	14.22	0.21
	Rx2	8.63	8.32	0.31
	Rx3	9.07	8.87	0.2
	Rx4	20.2	19.74	0.46
	Rx5	15.95	15.48	0.47
	Rx6	11.11	10.94	0.17
	Rx7	18.8	18.65	0.15
	Rx8	26.61	26.44	0.17
	Rx9	25.2	24.9	0.3
	Rx10	30.88	30.6	0.28
AP3	Rx1	24.82	24.62	0.2
	Rx2	19.56	19.33	0.23
	Rx3	15.15	14.95	0.2
	Rx4	21.47	21.34	0.13
	Rx5	7.33	7.045	0.285
	Rx6	13.74	13.45	0.29
	Rx7	19.97	19.55	0.42
	Rx8	24.34	24.29	0.05
	Rx9	26.19	26.01	0.18
	Rx10	27.18	26.99	0.19

The result of our proposed hybrid localization algorithm for each Rx point as compared with the actual coordination has shown an accurate estimation as seen in Fig 6 and 7 and for 2nd and 3rd floor, where the black circle represents the AP within fixed location, the blue plus sign represent the actual location of each Rx point (obtained from WI software), while the red circle represents the estimated Rx coordination (obtained from our algorithm). In addition to that, a brief analysis for the Rx coordination estimated from our proposed algorithm has been listed in table 6 and 7 for 2nd and 3rd floor respectively and along with the actual Rx coordination obtained from the WI software. As a result, ranging based error has been performed between this two coordination to indicate the higher accuracy and the effectiveness of our algorithm. It can be seen from table these both tables that the least ranging error was (0.04, 0.01) and (0.04, 0.03) m and the most ranging error was (0.36, 0.66) and (0.33, 0.89) m for 2nd and 3rd floor respectively. The average estimation error was (0.15, 0.23) m and (0.17, 0.28) m for the same sequence of the investigated floors. Indicating higher and reliable results in performing the localization within indoor environment.

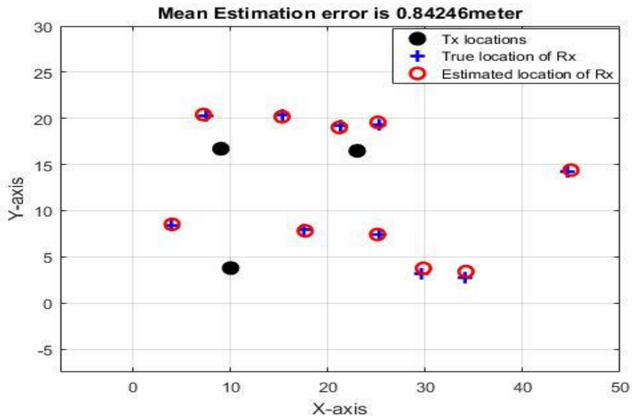


Fig. 6. The estimated Rx coordination vs. actual Rx coordination for 2nd floor Rx

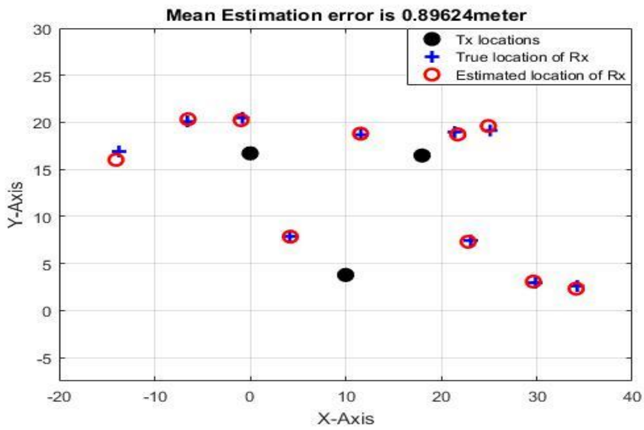


Fig. 7: The estimated Rx coordination vs. actual Rx coordination for 3rd floor Rx

Table 6. Comparison between the Actual Rx coordination and the estimated coordination per each Rx point for 2nd floor scenario

Received point	Second floor estimation					
	Act. Coordination		Est. Coordination		Ranging Error	
	x	y	x	y	x	y
Rx1	25.26	19.30	25.13	19.57	0.13	0.27
Rx2	21.29	19.23	21.16	19.01	0.14	0.21
Rx3	15.33	20.39	15.29	20.18	0.04	0.20
Rx4	7.49	20.28	7.21	20.41	0.28	0.13
Rx5	3.91	8.39	3.99	8.52	0.08	0.13
Rx6	17.53	7.97	17.66	7.81	0.12	0.16
Rx7	25.27	7.42	25.08	7.42	0.19	0.01
Rx8	29.67	3.18	29.81	3.76	0.13	0.58
Rx9	34.08	2.74	34.18	3.40	0.10	0.66
Rx10	44.60	14.22	44.96	14.38	0.36	0.16
Rx11	-13.62	17.58	-13.85	17.28	0.23	0.30

Table 7. Comparison between the Actual Rx coordination and the estimated coordination per each Rx point for 3rd floor scenario

Received point	Third floor estimation					
	Act. Coordination		Est. Coordination		Ranging Error	
	x	y	x	y	x	y
Rx1	25.13	19.14	24.94	19.61	0.19	0.48
Rx2	21.41	18.97	21.74	18.72	0.33	0.25
Rx3	11.60	18.68	11.56	18.80	0.04	0.12
Rx4	-0.81	20.48	-0.95	20.24	0.14	0.24
Rx5	4.15	7.88	4.20	7.85	0.06	0.03
Rx6	23.10	7.45	22.83	7.31	0.28	0.13
Rx7	29.87	2.96	29.65	3.08	0.22	0.12
Rx8	34.24	2.61	34.14	2.33	0.10	0.28
Rx9	-6.57	20.09	-6.51	20.33	0.07	0.25
Rx10	-13.73	16.91	-14.05	16.02	0.32	0.89

6. CONCLUSION

It this paper, it has been proposed a simple and cost effectiveness hybrid based ToA/ RSS localization algorithm to localize several Rx point for different IoT based applications. Rx points were localizing from 3 AP devices distributed within a regular indoor environment. Our proposed algorithm designed in MATLAB and based on the Gaussian Newton Algorithm for obtaining the coordination of x and y. The presented method had showed higher accuracy in estimating the Rx point coordination within both Line of Sight (LoS) and Non Line of Sight (NLOS), where it has taken in consideration an indoor environment consisting of two floors with effects of different building materials, obstacles and objects. Results obtained showed significant in obtaining both the estimated distance and coordination, where the least ranging error was (0.04, 0.01) and (0.04, 0.03) m and the most ranging error was (0.36, 0.66) and (0.33, 0.89) m for 2nd and 3rd floor. The average estimation error was (0.15, 0.23) m and (0.17, 0.28) m for the same sequence of the investigated floors.

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